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ON

'ENGINEERING OF PHOTOSYNTHETIC SYSTEMS'

(Volume 1)

A TOTAL-ENERGY and TOTAL-MATERIALS SYSTEM USING ALGAL CULTURES

1977

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PREFACE

Consider a village family. Concede them a liberal allowance of the following energy resources: (a) 1 litre of kerosene or 3 kilograms of coal per day, (b) two 40-watt bulbs burning 5 hours a day.

Now consider a thermal power plant generating net power of 100 MW. It will burn approximately 1000 tonnes of coal a day. The waste heat going out through the stack, usually about 6% of the energy in the coal, will amount to roughly 1700 GJ/day (1 Giga-Joule = 10^9 Joules). This amount of energy is equivalent to roughly what twenty thousand of our village families will use every day.

If we consider all our fertiliser plants, all our cement plants, all our blast furnaces, all our refineries, and of course all our power plants, the wasted energy in the stack gases can supply the energy requirements of approximately 10,000,000 village homes.

This monograph is not about the profligacy of modern technology, our legacy from the West. Nor does it talk about the wasteful, capital intensive systems being thought of to supply electrical energy to every village.

It is an attempt to integrate systems of sophisticated and appropriate technologies, marrying the vices of the former to the virtues of the latter.

The ideas in this presentation have been gathered over many years. They have been put together in a proposal-format. I recall with pleasure and gratitude the stimulus of working with my students,

Ravi Khanna, Anil Kohli, Satish Sharma, K.K. Sharma, M.B. Lal, Vijay Kirti, S.P. Singh, S.M. Mittal, Babu Joseph, Ajit Thakore, Santosh Kaul, T. Swaminathan, C.P.P. Singh, M.C. Misra. Besides these persons, I am indebted to many friends and colleagues, in particular, Sjts. S. Sampath, G.S. Venkataraman, C.N.R. Rao and W. Becker. I gratefully acknowledge the assistance of Sjts. K.R. Nagaraj and K.R. Kumar of Sunanda Aromatic Industries Ltd., Mysore.

Sri M.V. Murugappan, Member, Governing Body, Shri A.M.M. Murugappa Chettiar Research Centre, Madras, has through the aegis of the Centre, provided the time, money and encouragement to publish this monograph. I am indeed very grateful to him.

March 1977

Gokulam, Mysore
TIAM House, Madras

C.V. SESHADRI

PROLOGUE

Two questions face the modern Indian:

i) What is the optimum cultural energy input per unit of agricultural yield?

ii) At what rate should he use modern technology and at what price to achieve some predetermined state of national health?

The first question arises out of the fact that India is predominantly an agricultural country. The second question is one that confronts people of all developing countries, in fact people everywhere. Each key word in these questions is open to many meanings. The attempt to find answers to these questions at the national level is mind-blowing and rationale-shattering. Faced with the complex task of nation building, it is easy to confuse the search for the answers to questions such as those stated here with the questions themselves; or the means of attaining goals with the goals themselves.

What are the national goals and what are the means? The goals are simply stated - food without famine, fertility without fecundity, égalité without revolution. Achieving these goals and answering our questions are related problems; doing the latter task is one step to doing the former. The raison d'être of the questions are the goals. And nations march on their stomachs just as armies do.

The means are more difficult to define: to solve the stated problems they vary from the Gandhian concept of using low cultural energy inputs, low yields, high efficiency, high employment and ecological

viability, to the modern concept of using high cultural energy inputs, high yields, low efficiencies, high capital per unit of employment and possible ecological damage. The question is what is the optimal strategy, indeed what are the optimality criteria?

The present proposal is titled: "A total-energy and total-materials system using algal cultures". It is an attempt to integrate known technologies to grow a primary producer, which is useful for food, fodder, fertiliser and fuel. It attempts to use the wastes of sophisticated industry for an agricultural application. In doing so, it is hoped to combine the best of both sets of means stated previously. This kind of synthesis may lead to a better understanding of how affluent technologies can help sub-affluent peoples.

WHAT ARE TOTAL-ENERGY AND TOTAL-MATERIALS?

'Total-energy' usually refers to the maximum recovery of energy from central station power plants but nowadays it is applied to recovery of the energy from other industrial units also. Most conventional power plants operate in the efficiency range between 25-35% because a large part of the energy available in the fuel is thrown away as thermal pollution, i.e. in the stack gases, in condenser cooling water, in transmission losses, etc. As awareness of this wastage is growing, there are more and more plants being built to use this energy in the form of hot water, for space heating and so on.
What about the materials now being wasted in the same power plants? The phrase 'total-materials' is used here to signify a recovery system for the wasted materials. A 100 MW power plant burning coal

will discard about 2000 tonnes per day of carbondioxide, 7000 tonnes per day of nitrogen and 520 tonnes per day of water at stack gas temperatures. Besides causing unsightly pollution, these flue-gases tend to warm up the earth by the so-called greenhouse effect. The figures for cement plants, fertiliser factories, distilleries, etc. are also very large (Appendix II).

In the conventional power plant, the materials usage efficiency is close to zero, since the fly ash is usually considered a nuisance and is used mostly as land fill. The carbon dioxide is thrown away. The present proposal is designed to use both the energy of the stack gases and the materials, principally carbon dioxide, to fix the carbon in one of the most efficient photosynthetic systems known, i.e. algal cultures. Thus the combined materials - energy efficiency will be raised to much higher values than are now being realised.

CONCEPTS FROM MODERN AGRICULTURE

This section is a very concise introduction to some aspects of energy and materials usage in modern agriculture. There has been considerable work on the feasibility of energy plantations for obtaining liquid fuels from whole trees or parts of them. Calculations show that a plantation 11 KM square can fuel a 400 MW power plant (SE p.275)*; other calculations show that cultural energy inputs valued at US $ 300 per year could give a return of material costing US $ 10 per tonne biomass. The heaviest cultural energy inputs (about 57%) were for labour, fuel, chemicals (Biotech. Bioeng. Symp. - 1972).

In general, modern agriculture tends to use very heavy energy inputs

* See References

for the outputs obtained, as compared to primitive agriculture. Thus the output/input ratio for the latter practice can be as high as ten times that of the former (SE p.272). Such energy practices are very wasteful for poor countries. In this connection, an example may be given from rice or wheat cultivation. For the 35 million hectares of paddy cultivated, India's fertiliser-nitrogen production of 1.5 million tonnes in 1975-76 (India 5th V-Year Plan) amounted to only 43 kg. per hectare; this figure does not account for the wheat area. Now, the newer varieties of rice and wheat can absorb much higher levels of nitrogen-loading (than 43 kg.), to give correspondingly higher yields. Thus, cultural energy inputs in modern agriculture are not only wasteful, they are not even attainable in India due to foreign exchange and other limitations.

On the other hand, it has been estimated that about 3.5 million tonnes (Kapur - 1975) of organic nitrogen can be obtained through biogas plants operated only on cattle-waste. Hence, not only is more nitrogen available for organic fertilisation, it is also obtained at a low cultural energy level. An optimal mixture of the two modes of agricultural usage is necessary for long term benefits.

There has been some effort at genetic modifications to trees to make low molecular weight hydrocarbons for fuel use (Calvin - 1976). These attempts supplement the effort being put into conversion of cellulosic wastes into alcohol and methane (International Symposium - 1977). Other efforts at plant breeding that are of interest here are those made to reduce the differences between plants with a C_4-cycle and those with a C_3-cycle. Briefly, plants with a C_4-cycle are high

yielding varieties such as sugarcane, maize, sorghum, etc., can withstand higher light and thermal intensities, and have low photorespiration rates. Plants with a C_3-cycle have in general the opposite characteristics, thus cutting down yields (Fogg - 1976). One way of reducing the effects of photorespiration is to use higher CO_2 concentrations and lower oxygen concentrations (The Warburg Effect - Gibbs- 1970), to raise yields (SE p.281). It has also been demonstrated that higher carbon dioxide concentrations can help algal cells to withstand much higher light intensities (Fogg - 1976 p.5). There are thus two ways of improving biomass yield, one through purely biological means and the other through engineering practice. For algal cultures, which are submerged cultures, many engineering techniques are available for taking advantage of the cells' response to their ambience; some of these have just been pointed out. Yet another technique is to submit the culture-cell mix to light-dark programming to raise biomass yields (for reviews, see Seshadri and Misra - 1977, Misra - 1976, Fogg - 1976 p.87).

WHY ALGAE?

Algal cultures have several advantages over conventional plants viewed from the purely agricultural view point. However, post-harvest technology being expensive, it has not been possible to propagate their widespread use for food supplements. Some of these advantages are:

1. High output per hectare, thus minimising land usage (Appendix I).

2. Low water usage per unit of useful biomass yield (Oswald in Mateles - 1968).
3. Whole-cell or whole-plant utilisation (Becker - 1976).
4. High protein and vitamin output per hectare (Appendix I).
5. Since cultures are usually carried out in liquid media, several engineering improvements are possible.

For food use, the standards of permissible contaminants are very rigid, hence the biomass has to be thoroughly dry and free of salmonella and other organisms. Moreover, the cell-wall has to be broken down for digestibility. This requires high temperature processing in expensive equipment. It is unlikely that algae not grown on waste carbon dioxide and not using low-grade energy resources can be made competitive with other sources of equivalent foodstuffs. Algae grown for fodder can be made cheaply, especially for cattle-feed. Here the cellulose is broken down in the rumen, hence a concentrated slurry can be harvested and distributed for feeding purposes. For poultry feed, it is again necessary though not vital to break down the cell-wall of the cells for easy digestibility (see Becker et al - 1976).

The RNA content of algal foods are not very high in comparison with other single-cell proteins. To stay within the PAG guidelines of FAO, Rome (2g/day person of RNA), about 50g/day of algae may be ingested. So we can safely work at levels of 25g - 40g/day person for balancing diets with algae dry matter.

Some blue-green algae have been shown to fix nitrogen of the atmosphere (G.S. Venkataraman - 1973). In India, there has been considerable

effort put into propagating algal biofertiliser; this becomes particularly relevant in view of the continuing shortfall of inorganic fertiliser pointed out in the previous section. Algal species alone or in mixture with azolla cultures are being cultivated in pilot plants in India (G.S. Venkataraman - 1977). It has been demonstrated that these species not only contribute nitrogen and oxygen to paddy-roots but also condition the soil. The requirements of sterility of the cultures are easily controlled by untrained workers, hence this kind of culture lends itself to widespread dissemination. The Indian Agricultural Research Institute has a culture-collection and they supply both cultures and inoculum for experimental purposes.

The energy use of algae is best done through growth on domestic effluent, anaerobic fermentation to methane and subsequent combustion in a power plant, with recycle of all components, including carbon dioxide. Such a scheme was suggested by Oswald (1960). It is not known whether this scheme has been actually implemented. Being a prolific organism (along with water hyacinth and sugarcane) large tonnages can be grown on waste domestic effluents and other organic wastes, e.g. distillery-spent wash, etc. The use of organic effluents, both domestic and industrial, for the cycle man-waste-algae-fish-man has received considerable attention recently (Ong - 1976, Sundaresan - 1977, etc.). There are several such schemes in execution in Malaysia, New Guinea, etc. These schemes offer hope for the dual purpose of food and getting rid of the effluent nuisance.

WHAT THIS PROJECT IS DOING

The Primary Objective is to carry out feasibility studies and to set up a pilot facility to produce 1 tonne per day of food or fertiliser grade algae dry mass using the waste materials and energy of large power plants. It is assumed that food and fodder grades are interchangeable if the standards are maintained.

The Secondary Objective is to disseminate the use of the products of the facility and the techniques used here.

The Tertiary Objective is to integrate aspects of low cost technologies and to minimise capital investment per work place so as to employ as many skilled and unskilled workers as possible.

The division into objectives is arbitrary and is not the basis of priorities. The attempt has been to think in terms of integrated systems of technologies to maximise the common good.

METHODS OF ENERGY AND MATERIALS RECOVERY

Basis: 1 tonne per day of algae dry mass.

Assumptions:
1. Pilot plant works 300 days per year.
2. Average growing period 250 days per year.
3. Average yield 20 gm/m^2 day.
4. CO_2 utilisation efficiency is 10%.
5. Algae contains 0.5 fraction carbon.
6. Flue-gases essentially ash-free and free of NO_x, SO_x.

Assumption (1) is self-explanatory. Assumption (2) is an allowance based on cloudy days, monsoon and other inclement conditions. Assumptions (3), (4) and (5) are justified in Seshadri and Misra - 1977 and Misra - 1976. These are also standard conditions and are conservative assumptions; for example 20 gm/m^2 day over 250 days amounts to

only 50 tonnes/ha. year. This is a median value for algal cultures which range from yields of about 20 tonnes/ha. year to about 80 tonnes/ha. year (SE p.278). The flue gases in modern plants are cleaned by precipitators and are pollutant free due to more efficient combustion (Bienz J. and H.N. Sharan - 1977 and Times of India - 1977).

Area needed for submerged culture

10^6(gm/day) $\div$ [(20 x 10000) (gm/ha.day)] = 5 hectares

C in algae = 0.5 tonnes per day.

By Assumption (4), CO_2 = (0.5) (44/12) (1/0.1) = 18.3 tonnes per day.

Flue Gases: Assume a flue gas of the following composition by volume -

CO_2 : 0.14; H_2O : 0.08; O_2 : 0.04; N_2 : 0.74

Appendix II gives the justification for this assumption.

Average molecular weight of flue gas:

0.14 x 44 + 0.08 x 18 + 0.04 x 32 + 0.74 x 28

= 29.6 (compared to 28.8 for air)

Quantity of flue gas/day = (18.3) (29.6) / (0.14) (44)

= 90 tonnes per day.

Assume: 1) a specific heat of 0.2 kcal/kg K.

2) a flue gas temperature of 550 K and a lower rejection limit of 320 K. These are justified if there is a waste-heat recovery system and on the basis of an ambient temperature of 32 C with a 15 centigrade degree-approach (Waste Heat Recovery - 1963).

Enthalpy in flue gases

(90 t.p.d.) (1000 kg/tonne) (0.2 kcal/kg K) (230 K°) (4187 J/kcal)

$\simeq$ 17 GJ/day $\simeq$ 4.7 MWH/day.

This enthalpy is only in part of the total flue gases; total enthalpy rejected is about 500 MWH/day.

<u>**Methods**</u>: Four systems are discussed here:

a) Energy is first recovered, then materials.

b) Energy is first recovered, then only carbon dioxide is recovered.

c) Energy and materials are recovered simultaneously.

d) Delivery systems for materials.

The first three systems are presented schematically in Figure 1. The delivery system, being almost common to all three systems (a), (b) and (c), is discussed very briefly, separately. Figure 1(a) shows a system of storage of the energy in a reservoir and cooling the gases to some reasonable temperature, followed by perhaps a water spray to cool it to ambient temperature. The gases are then sent via the delivery system to the culture facility. The storage of energy can typically be in a pebble-bed system or in other heat storage materials like Al_2O_3, the energy to be subsequently recuperated by an air-stream for drying of the algae or other purposes. To begin with, it is proposed to use motors and blowers to transport the gases. But since there is a large amount of energy available in the gases, there seems to be no reason why ultimately Stirling engines (Diamant - 1970) or Fluidyne devices (SE p.211) cannot be incorporated to conserve the energy being thrown away. These are indicated by dotted lines in the diagram. Thus, the energy flow shown is not only a direct use, principally for drying, but also indirectly as the drive for various pumps and blowers. It should also be pointed out that direct flue-gas drying of algae is possible, without the use of intermediate storage. Figure 1(b) shows a schematic of a system where only the CO_2 is used. The choice, of course, has to be based

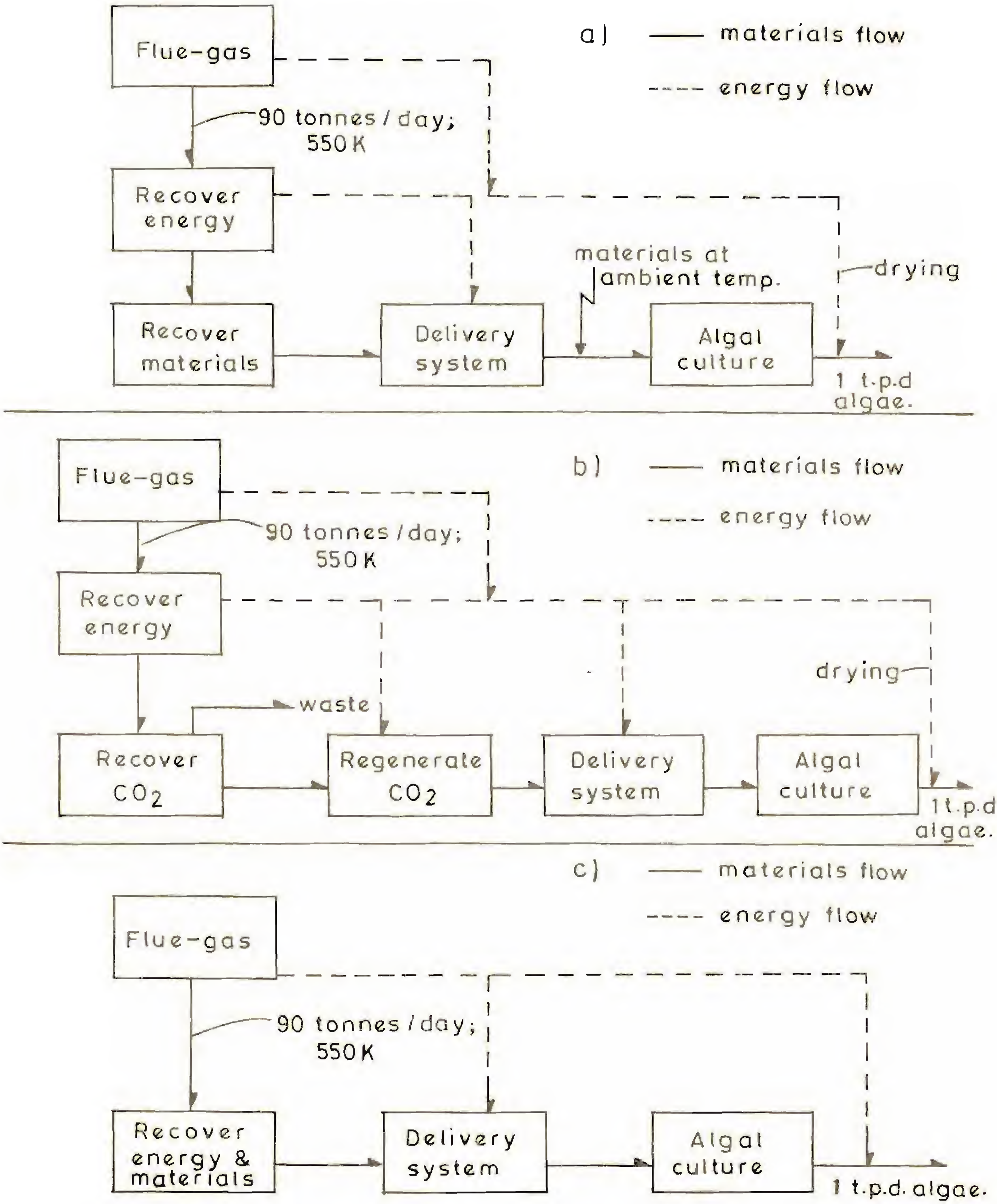


Figure 1. Scheme of recovery systems.

on the economic return on the process. Here the regeneration of carbon dioxide from its absorbent is shown as a separate block. The common absorbents are molecular sieves, monoethanolamine or aqueous carbonate-bicarbonate mixtures (Sherwood, Pigford, Wilke - 1975). These have to be treated to regenerate the absorbent and to release the gas. The delivery system will handle less gas here.

Figure 1(c) shows a recovery of both the energy and materials simultaneously and some detailed calculations and advantages and disadvantages are discussed here. In working out the economics, considerable analysis and experimentation will be necessary to decide on a choice of system.

The rest of this section is a salient feature of this proposal and is discussed at length. It embodies the idea of an 'energy-balloon' which can be used to store the stack-gases and carbon dioxide at 550 K and near atmospheric pressure, under conditions of neutral buoyancy. The balloon can be transported to sites other than the algal culture system because of its buoyancy and used on other C_3 or C_4 crop-plants also. It can incorporate solar-photovoltaic modules to generate electricity at agricultural sites. It can generate a considerable employment ~~potentially~~ potential depending on the economics and the price one is prepared to pay for tangible and intangible benefits.

Consider the stack-gases; they have a molecular weight of 29.6. Therefore, even at atmospheric temperatures they will be almost neutrally buoyant. Stored in an insulated balloon at elevated

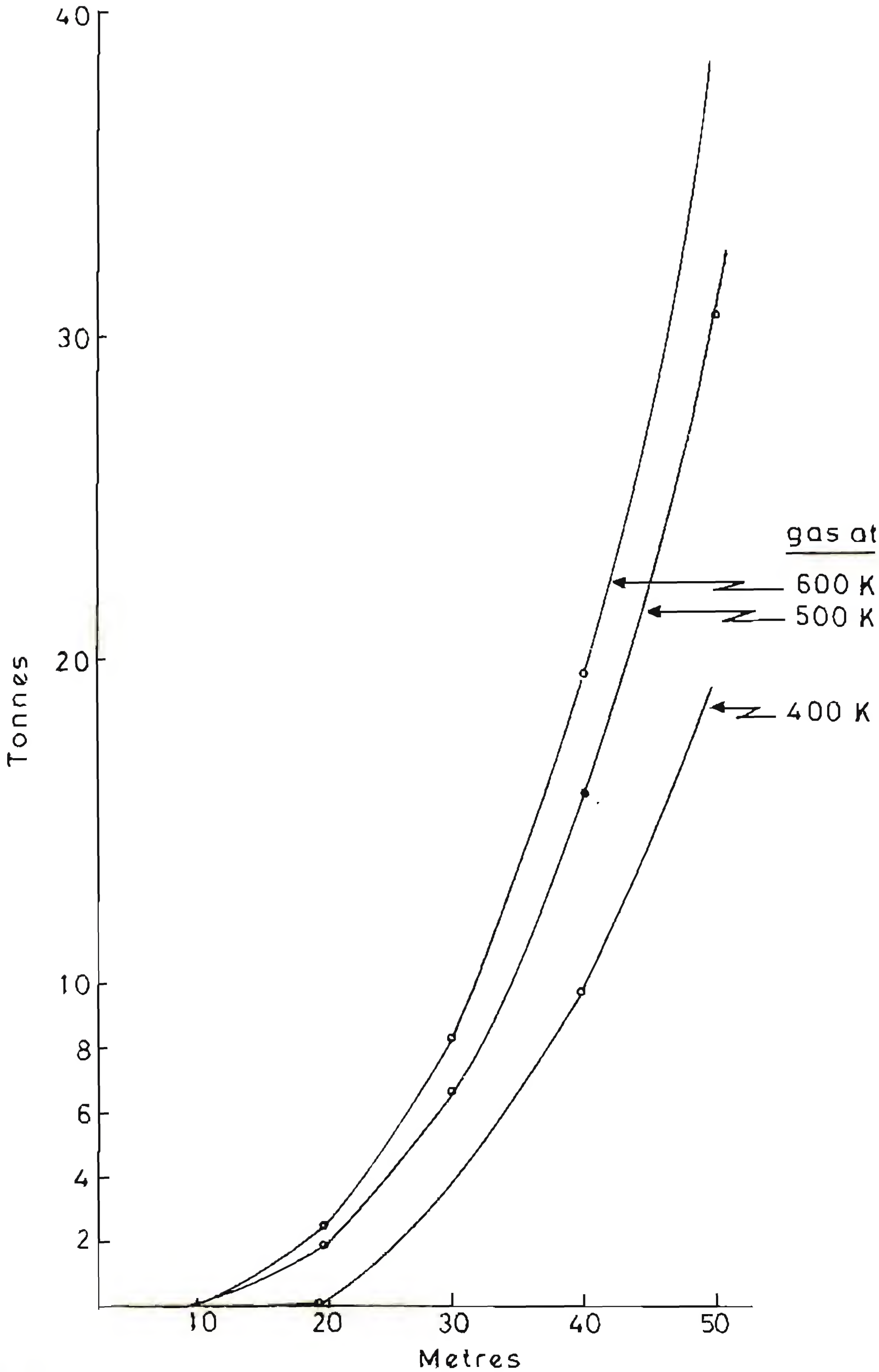


Figure 2a. Assume spherical balloon. Mass of balloon materials (if ambient air = 300°K) versus balloon diameter. Gas molecular weight = 29.0.

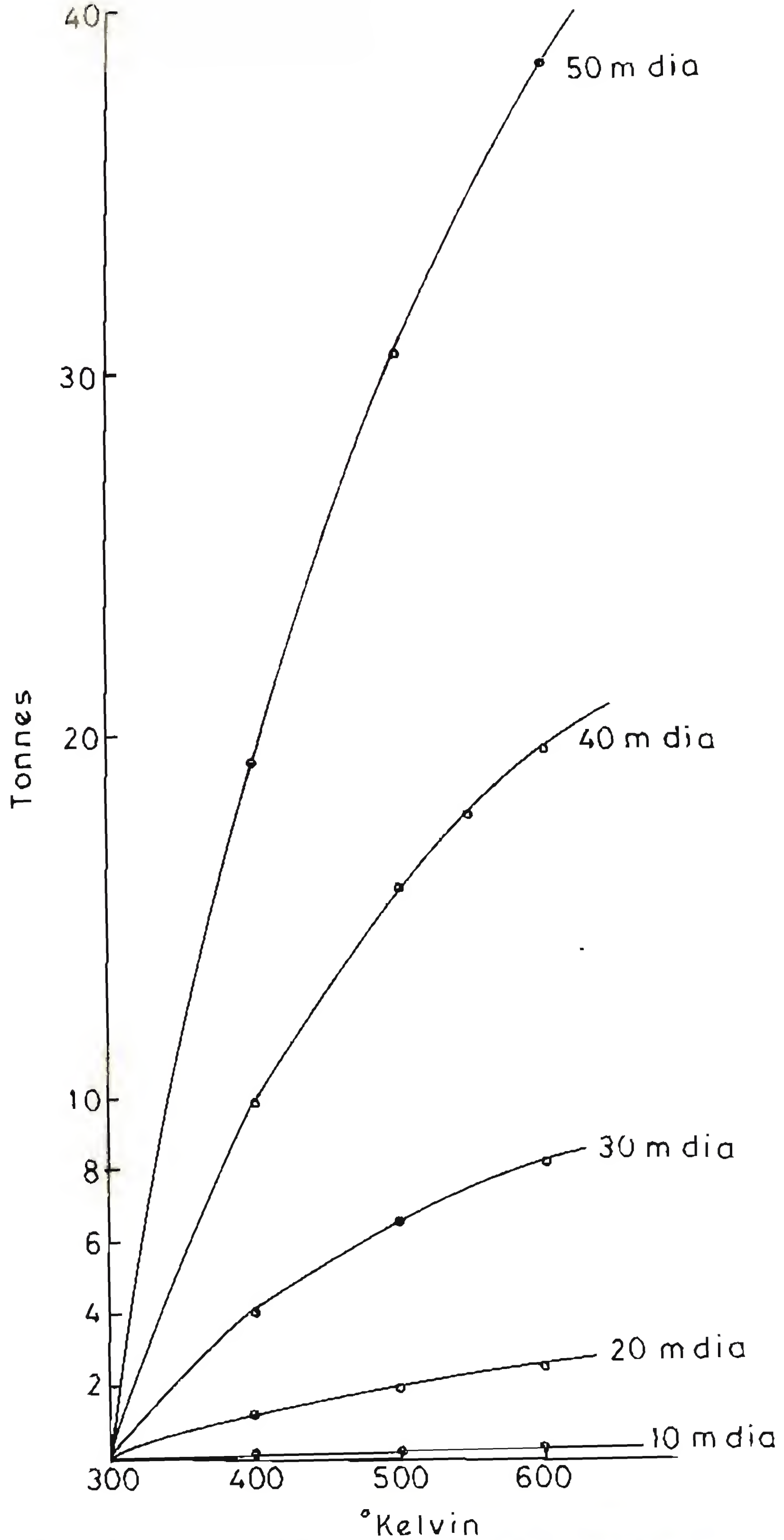


Figure 2b. Assume spherical balloon. Mass of balloon material (if ambient air = °300 k) versus temp. of gas. Gas molecular weight = 29·0

TABLE 1

VOLUMES AND MASSES OF BALLOON AND GASES

Diameter Meters	Volume $Metre^3$	Area $Metre^2$	Displaced Air Tonnes	400 K Gas Tonnes	400 K Balloon Tonnes	500 K Gas Tonnes	500 K Balloon Tonnes	550 K Gas Tonnes	550 K Balloon Tonnes
10	524	314	0.62	0.46	0.16	0.37	0.25	0.34	0.28
20	4192	1256	4.90	3.70	1.20	3.00	1.90	2.70	2.20
30	14156	2826	16.70	12.50	4.20	10.00	6.70	9.10	7.60
40	33510	5024	39.50	29.60	9.90	23.80	15.70	21.50	18.00
50	65450	7850	77.10	57.90	19.20	46.50	30.60	42.10	35.00

Conditions: Ambient air 300 K ; MW of gases 29.00 ; p = 1 atmosphere.

temperatures, they can serve to overcome the weight of the balloon-material and tether-system. These calculations and other designs are discussed below.

Figures 2a and 2b show the graphs of allowable masses for balloon materials (including tether) versus diameter and versus temperature, with the other variable as parameter, in order for the balloon to have equilibrium buoyancy with an ambient at 300 K. The other conditions are as shown there. The amount of gas held at various temperatures and in various diameters are shown in Table 1. The dew-point of the moisture in the gas is well below the present temperatures (550 K), hence should not pose a problem in altering the gas density, i.e. 8 volume per cent water has a saturation temperature corresponding to about 330 K.

As seen in the graphs of Figure 2, the material of the balloon and tether system can be quite substantial. A range of 13 - 15% CO_2 is usual for fuel oil and coal burners. The temperature and pressure chosen here, 1 atmosphere, are quite arbitrary; however these conditions are close to what one may expect in practice. For other conditions of temperature, composition and pressure, the calculation is quite straightforward. The point to note is that even at, say, 400 K a 30 m - diameter balloon allows us about 4 tonnes of balloon mass.

In this zeroth iteration, the optimal configuration and size have not been determined. Such calculations will have to take into account the cost of energy saved, cost of materials and labour, depreciation and interest on fixed assets, pay-back on product and charge-back on

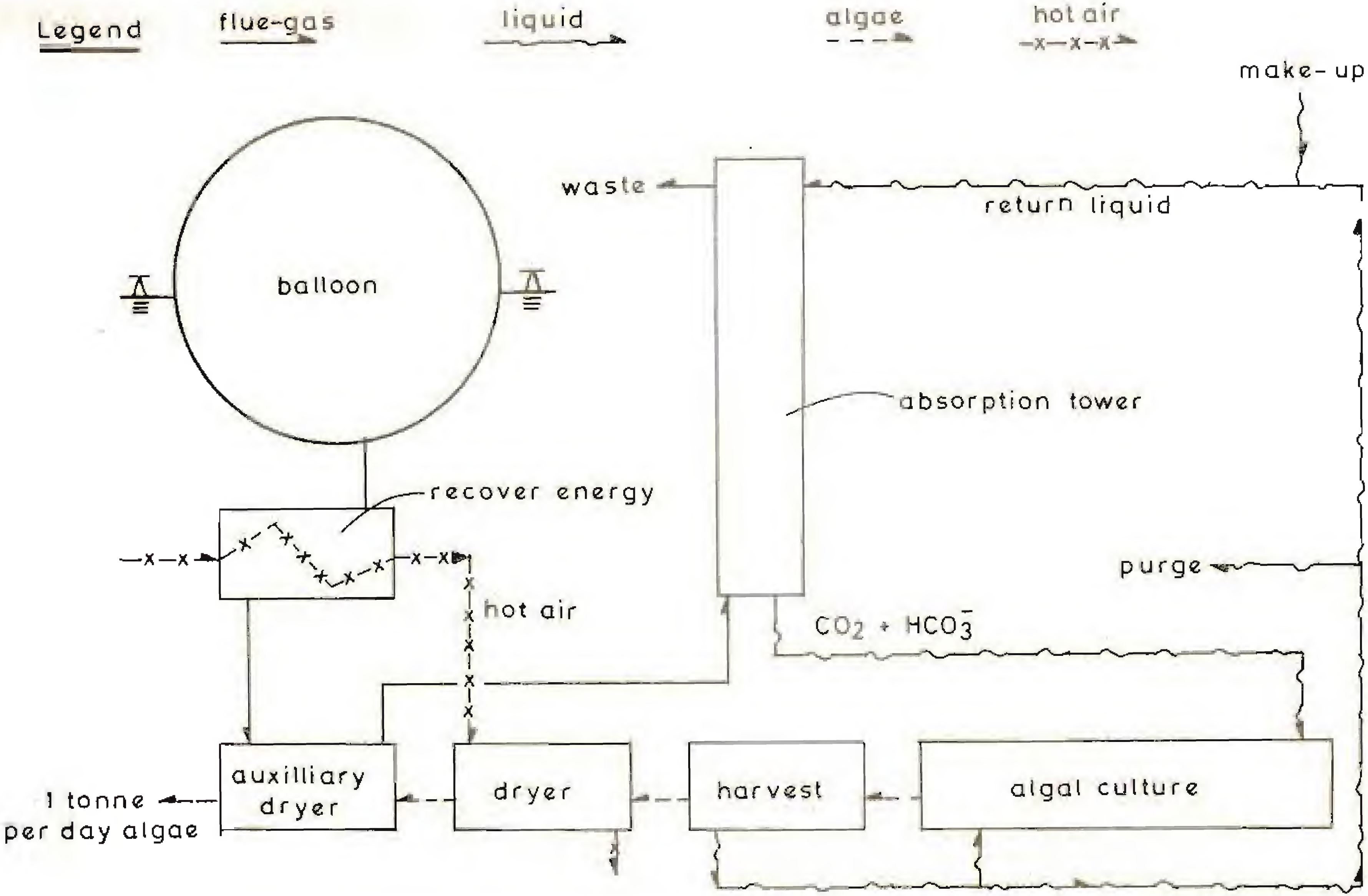


Figure 3. Scheme for integrated system including a balloon.

the power plant (if allowed). For the present, we choose a balloon of diameter 40 m, storing or receiving gas at 550 K, and 1 atmosphere pressure.

From Table 1 and Figure 2a and 2b:

Volume of balloon: 33510 m^3

Area of balloon: 5024 m^2

Mass of gas (MW=29) at 300 K displaced - 39.50 tonnes

Mass of gas (MW=29) at 550 K - 21.50 tonnes

Balloon material allowable - 18.00 tonnes

To supply 90 tonnes per day, we need 5 balloons or 5 charges of the same balloon. It can be seen that a 50 m balloon will hold about twice the mass but needs only about 1.5 times the material. Thus for an equivalent mass capacity, the skin density of the balloon can be greater for a 50 m balloon. Preliminary calculations show that an uninsulated balloon will lose heat faster than gain it by solar irradiation.

Figure 3 shows a schematic of the recovery system for energy and carbon dioxide once the balloon is filled up. Blowers (not shown) take the gases from the balloon through a heat recovery system and then through an auxiliary drier and the CO_2 absorption system. The CO_2 absorption works on the principle of the reaction:

$$2HCO_3^- = CO_3^{2-} + CO_2 + H_2O$$

Algae such as Spirulina Platensis and Scenedesmus Acutus, can be grown on high bicarbonate concentrations. The liquid after absorption

of CO_2 is pumped back to the culture. After the culture is harvested, the algae is dried and packaged.

It has not been possible to work out the cycles or equipment sizing. The amount of gas to be discharged from the balloon is also not known at present. If the balloon is to be used at site it need not be insulated. As a matter of fact, the balloon need not even be buoyant, if it is to be used at site. Its convenience lies in being able to use it whenever needed.

For uses at remote locations, the material of the balloon must have the following properties:

a) Insulate
b) Withstand 500 - 600 K
c) Be tough for repeated usage
d) Be within the weight limit until most of the gas is exhausted
e) Lend itself to adaptation for photovoltaic modules.

The last requirement is a refinement which is not immediately germane to this project. The other uses to which the energy can be put at other locations are:

a) Thermal energy can be traded off for electrical energy.
b) For use in community kitchens.
c) For agricultural drying.
d) For air-conditioning for comfort or storage.
e) For engines and pumps.
f) For heating biogas plants in winter in North India.

Figures 4a and 4b show two types of balloon-material. These are designed for insulation and have to be made of heat resistant film, i.e. aluminised mylar, modified polypropylene, Kapton, silicones, etc. Figure 4a is essentially two layers of plastic with air bubbles in between as in packing materials for shock-resistant packing. Figure 4b has 'ballotini' balls acting as an insulating layer; these are used in space applications. Figure 4c is the same as the others except a CdS polycrystalline coating (SE p.231) with a Cu_2S layer covered with a sealant. These cells can be made cheaply on a large scale (SE p.232). The balloons will obviously have to be transported back and forth for recharging and these costs will have to be added on.

Some numbers

Two grades of polythene film are sold in India. Other types of film are not made. Rubberised canvas is available, but this is a special item. Based on the properties of polythene film, some rough estimates are given for the 40 m balloon.

UNION CARBIDE (INDIA)

Film qualities: 100μ and 175μ thick.

Sold in 8 m x 8 m width; 10 square metres weigh 1 kg.

Price/kg. of 100μ film: Rs.18/kg.

Price/kg. of 175μ film: Rs.32/kg.

Area of balloon: 5024 m^2

Therefore cost per layer of 100μ = Rs.9,043/-

Each layer weighs only 500 kg.

Figure 4a. Skin of balloon with air bubbles.

Figure 4b. Skin of balloon with 'ballotini'- plastic balls.

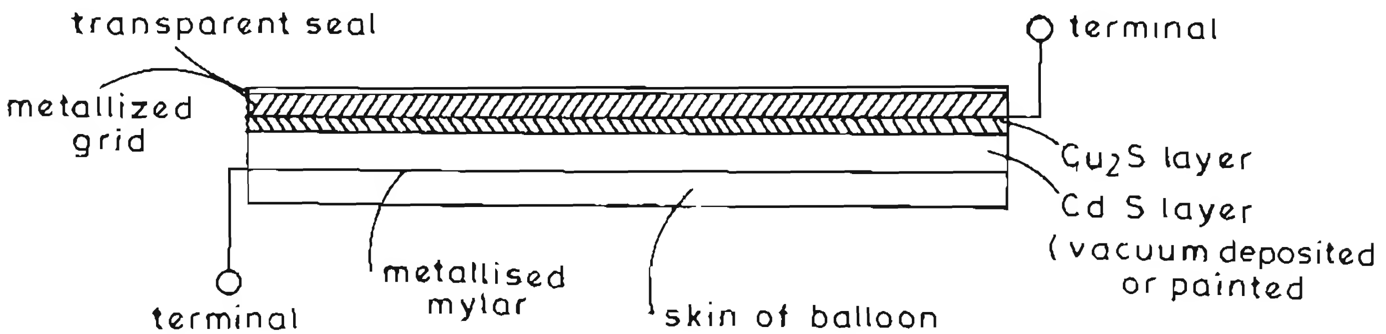


Figure 4c. Photovoltaic module on balloon

Assume each balloon of proper material plus manufacture will cost Rs.45,000/-. Assume (a) cheap solar modules of efficiency 0.01 - this is a low efficiency compared to the ones available, (b) average insolation of 251 WH/m^2H (SE p.239), (c) 8 hours per day operation, (d) collection efficiency of 50% in batteries, (e) 800 m^2 effective area, i.e. less than half-sphere. Then generated power per day:
251 x 0.01 x 0.5 x 8 x 800 = 8 KW.
The average Indian price for a diesel set is Rs.1500 - 2000 / KVA. Therefore, price per kilowatt is 45000 / 8 KW = Rs.5600. In areas where there is no electricity or facilities available, this may be useful. The estimates have been made very conservatively.

Some ideas about delivery systems have already been discussed. Either the gases can be used directly after cooling or the absorption cooling of CO_2 must be carried out and then used in solution or again regenerated. In this we are fortunate that bicarbonate system with absorbed CO_2 is one that can be used by algae directly. Hence, part of the material can be recycled to reabsorb CO_2 after growth utilisation of the carbon, and then pumped back to the algae ponds. If the nutrient is still too hot, it can be ponded and used after cooling. ~~This~~ That is, the CO_2 required can be absorbed at night, cooled and used during the day for photosynthesis. Thus several possibilities again suggest themselves.

In general, if the gases are to be used directly, they can be sparged into the algae culture units through perforated pipes, or if a transparent cover can be provided, they can be fed directly into the air-space above the culture units. In summer, when there is a danger

of light saturation, the tanks can be covered with cheap thatching of coconut or cane and the ~~gasses~~ gases fed into the air-space. The coconut thatching will allow enough light (as in Indian nurseries) for growth. Thus, pipelines have to be laid to feed the gases to all the culture units.

If the choice is to feed the CO_2 dissolved in the medium, then a return line to carry part of the medium, after filtration, to the absorber is necessary. One advantage of the energy excess is that in the North Indian winter the cultures can be kept warm by circulating either hot gases or hot nutrients. All the above alternatives will have to be explored.

ALGAL CULTURE UNITS

Figures 5a, 5b, 5c and 6 show some algal culture systems that the author has experience with (see also Appendix V). Figures 5a and 5b show a facility extending over 1 hectare. It was designed to treat the effluent from a yeast factory after dilution. The initial aeration and recirculation cascades are shown with a distribution system for the effluent. The cascades were made on hard ground packed with pebbles to maximise turbulence and minimise seepage. The sides were lined to the height of approximately 1 metre with flat stones rammed into an earthen bund. The whole facility cost about Rs.20,000 to prepare. It consisted of a 30 m x 30 m cascade system followed by 4 tanks of about 9000 m^2 area; all sides were lined. The author's assistants are shown in the figures.

Figure 5c shows a facility available through a German (FDR) grant

FIG-5A

FIG-5B

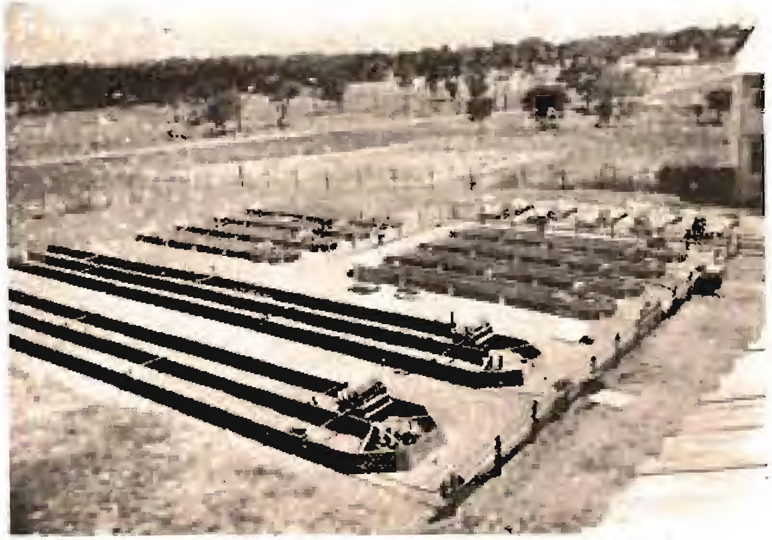


FIG-5C

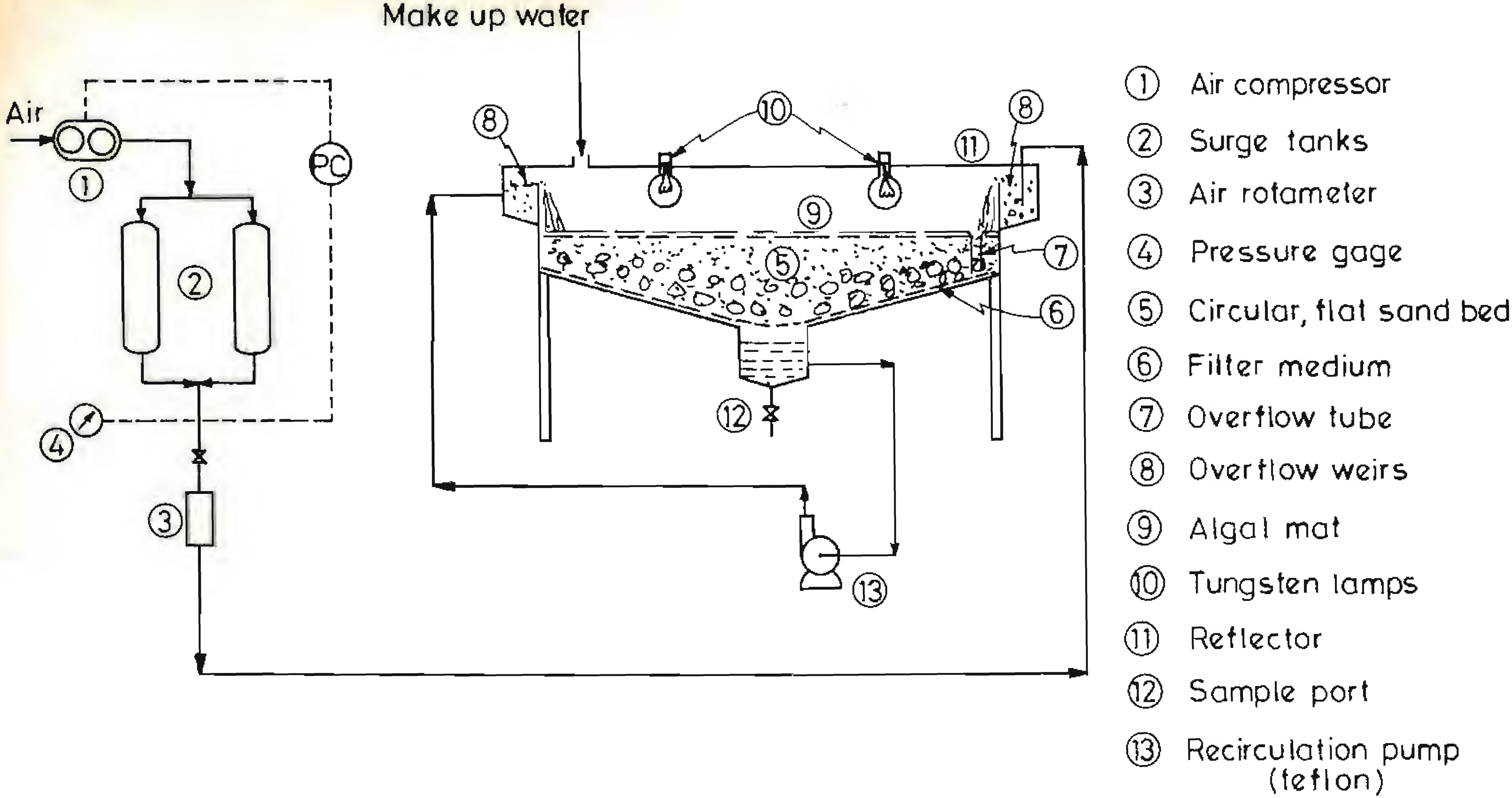


Figure 6. Circular, flat sand bed for solid culture.

to the Government of India at Central Food Technologies Research Institute, Mysore. It consists of a PVC-lined trough with motorised paddle-wheel stirrers. Connections for sparging air, CO_2, etc. were available. Each of the tanks shown were 50 m^2 in area.

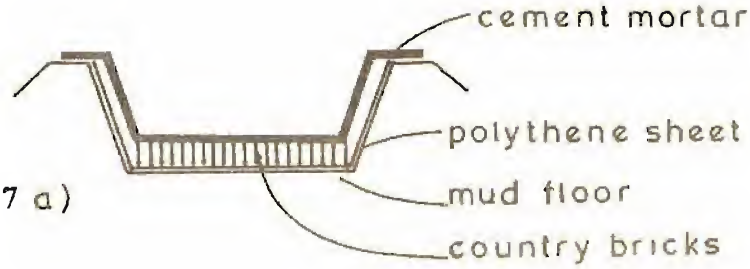
Figure 6 is a solid-bed culture for blue-green algae, since here the sand-algae mixture can be sold as inoculum to farmers for fertilisation. It was carried out in artificial light and has a CO_2 sparging system.

Algae need the following nutrients in sunlight:

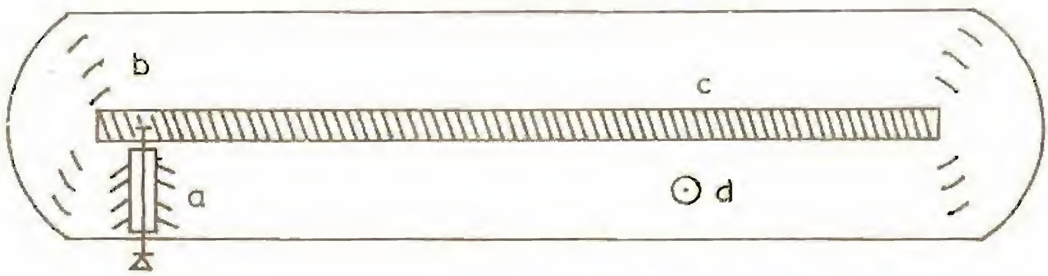
1. Water, which can be re-used after harvest.
2. A carbon source.
3. A nitrogen source, unless they are nitrogen-fixing.
4. Phosphorous.
5. Trace elements.

The usual practice is to inoculate a tank or bed with enough inoculum to avoid photo-oxidation and to overwhelm other organisms that may be present. Stirring of the cultures is necessary to prevent mites, etc. from settling in the tanks and eating the algae and to keep the cells supplied with oxygen at night.

Though there are several designs available, only two are discussed in this proposal. Figure 7 is a design for a submerged culture unit and Figure 8 that for a solid-bed unit. Figure 7a shows a detail of the tank construction. It has been determined that the cheapest construction is to lay a polyethylene sheet, then a layer of country bricks on end and then use cement mortar to seal up the bricks. A water-proofing

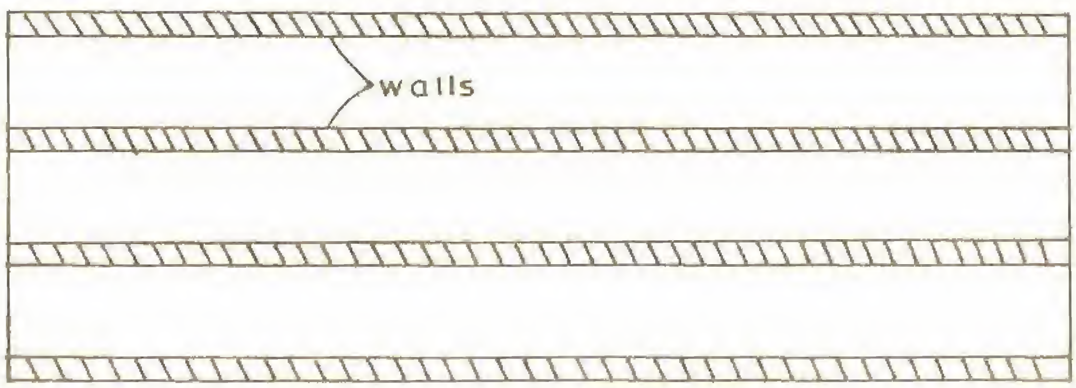


7 a)



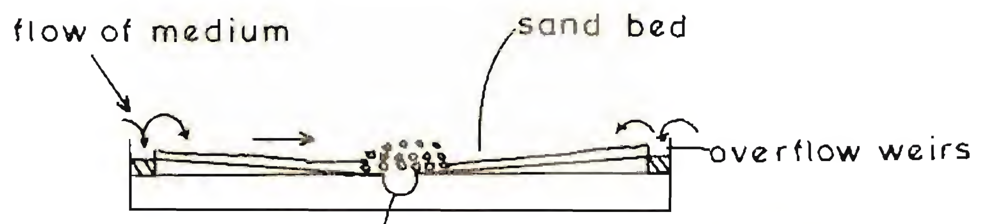
7 b) (not for scale)

a) agitation device
b) baffles
c) diriding wall
d) drain

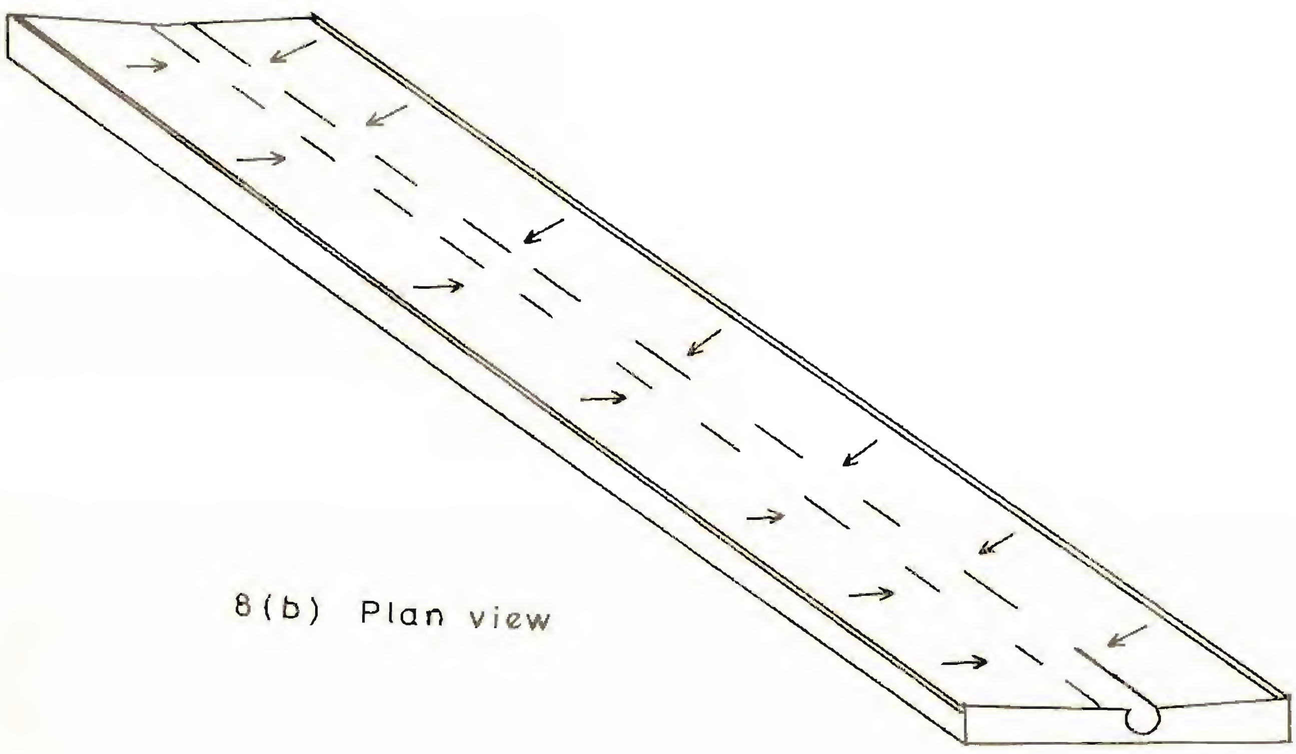


7 c) Tanks sharing walls.

Figure 7. Submerged culture tanks



8 (a)



8 (b) Plan view

Figure 8. Solid beds for algae

cement also helps to prevent seepage. This construction is very cheap and can be carried out by semi-skilled labour. A thatched roof over the tank may or may not be used in summer. The other details of the tanks are shown in figures 7b and 7c. The usual design is in the shape of an oxidation ditch with manual, animal or power driven paddle wheels. Two outlets, one of them a drain and baffles for smooth flow at the corners, complete the design. Figure 7c shows several long ponds showing common walls to cut down the costs. In this case, the agitators have to be designed such that manual labour can be used to draw a paddle device down the length of the tanks. Cheap materials, e.g. bamboo, are used to make the paddle wheels.

Another way of agitating the cultures is by pumping the fluid from one end to the other. An added advantage here is that the carbon dioxide laden nutrient can be mixed very efficiently. In evaluating costs, the net worth of human labour has to be offset against the cost of power and materials cost. Arrangements for sparging CO_2 or adding nutrients in liquid are not shown, but have been discussed previously.

Figure 8 shows an elongated solid bed culture that is planned for fodder and fertiliser grade algae. The principle here is that the liquid medium with nutrients is passed over the cells trapped in a solid matrix. These solid beds provide a large surface area for growth and obviate the need for expensive separation of the cells from the medium. The solid materials with algae are used as such.

The sloping sides of the beds in the figure, carry the solids and the central channels collect the liquid after percolation, for being pumped

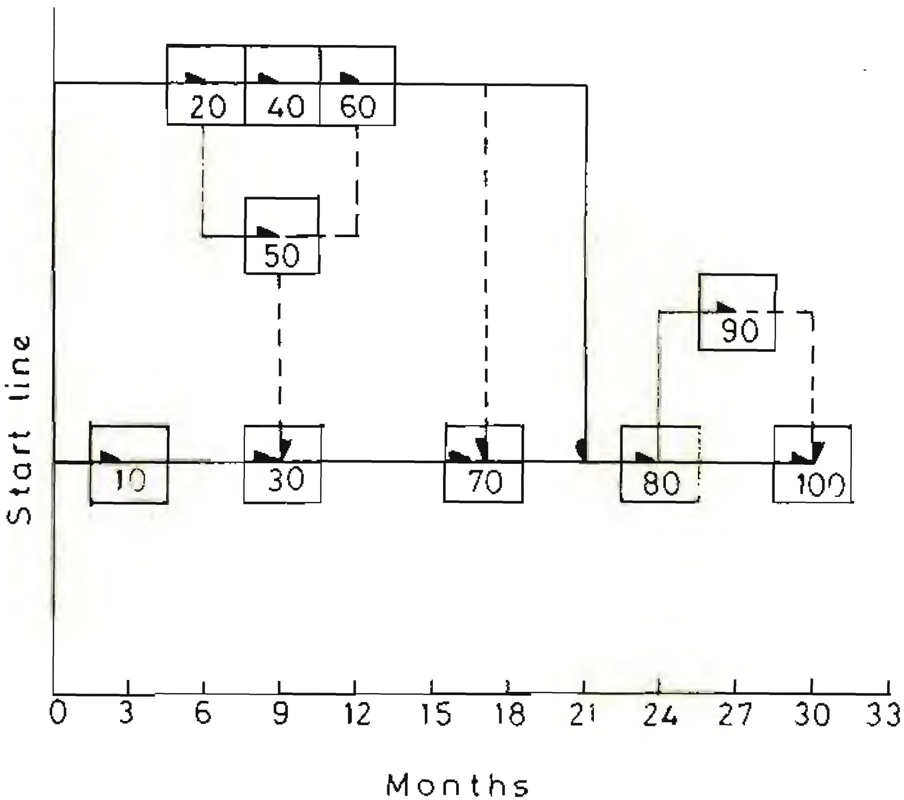
back to the bed or for reabsorption of CO_2. The solids that can be used are sand-fly ash mixtures and granulated dried compost for fertiliser grade algae and bagasse pith and other agricultural residues for fodder grade algae. For food grade algae, the slopes are left bare.

The best species to grow are spirulina or scenedesmus for food and fodder, and blue-green algae species such as Nostoc, Tolypothrix, Anabaena, etc. for fertiliser. The big advantage of spirulina is its large cell-size and therefore ease of filtration. Unless grown on some kind of solid matrix which can easily be used in toto, other species such as scenedesmus are very difficult to separate and need expensive equipment. Autoflocculation followed by decantation offers the best hope for use as cattle feed. The blue-green species are to be used after sun drying along with the sand or compost matrix. So harvesting here is minimal.

To dry very wet materials, a continuous multistage fluid-bed drier offers the best solution. Such a drier has been made in India for active yeast manufacture. The algal cells, however, need not be viable, so higher temperatures can be used. Drum driers or spray driers are very expensive and therefore are to be avoided unless absolutely essential.

SCHEDULING AND PRELIMINARY COST ANALYSIS

This section contains a critical path method (CPM chart) and a preliminary cost analysis. The critical path is for the establishment of the pilot plant. The cost analysis is estimated to be reasonably accurate at present-day prices.



10. Data collection & Analysis

20. Obtain Licences & Sanctions

30. Design recovery plant for energy & Materials

40. Purchase land for Culture

50. Hire Personnel

60. Set up Culture units

70. Set up Pilot recovery unit

80. Test & Commission total system

90. Trial runs for Demostrations & Costs

100. Feeding & Other trials

☐ Each square represents the end of an activity

--- Dummy activity

—— Real activity

Critical path -10-30-70-80-100

Figure 9. Critical path analysis for setting up pilot plant.

The CPM chart has been drawn on a time scaled plot - Figure 9. The algal culture facility has been independently set up even before the recovery system is completed so that the training of the large number of personnel can be undertaken. The most optimistic time along the critical path is 30 months. Due to the new technology, large variances should be allowed in these estimates. The most pessimistic time is 40 months.

The cost analysis is based on submerged culture tanks. It is also based on an artificially pegged price of Rs.4/kg. algae. This is about one-third the price of equivalent meat in India. For fodder algae it is a high price if we compare it with oilseed cake. Considering the inoculum value of fertiliser grade algae, the price is low, though there is no data available on the subject. Straight line depreciation over 10 years has been used since the preliminary analysis is based on a simple pay off. There is no charge-back on the power plant for pollution.

Analysis:

Algae mass per year: 250 000 kg.
At Rs.4/kg. return = Rs 1 000 000
Children fed at 25 gm/day = 27 000/day

Investment:

	Rupees
Land 8 ha. @ Rs 25 000/ha.	200 000
Tanks 60 000 m^2 @ Rs 20/m^2	1 200 000
Piping 5 000 m @ Rs 20/m average	100 000
Building 500 m^2 @ Rs 400/m^2	200 000
Laboratory equipment	100 000
Blowers and motors 4 Nos. @ 100 000 each	400 000
Towers and other equipment	300 000

	Rupees
Valves and fittings	200 000
Electricals	200 000
Labour for erection (other than building)	200 000
Contingencies	200 000
Say	3 300 000

Costs:

Depreciation over 10 years	330 000
Electricals 400 KVA	75 000
Water and Chemicals	300 000
Labour 200 @ Rs 200/month x 12 months	480 000
	1 185 000

The plant makes a loss of Rs 185 000 per year. However, an artificially low price has been chosen. In spite of this, the loss is only about Rs.500/day or Rs 0.02/child-day. More realistic costing of products and plant is bound to bring the prices closer to each other.

SUMMARY OF TECHNICAL DETAILS

1. Systems have been described for recovering energy and materials from thermal power plants for growing algae and harvesting the bio-mass.

2. The concept of an 'energy-balloon' has been propounded. These balloons can also be used at remote locations for thermal energy and carbon dioxide. Their surfaces can be used for photovoltaic modules.

3. Algal culture units have been proposed.

4. A cost analysis and a schedule are proposed for a 1 tonne per day pilot plant.

EPILOGUE

This proposal has outlined one way by which pre-Industrial Man can ✓ use the wastes of Industrial Man to make a post-Industrial product. The former with his considerable traditional skills can thus find a way to use them in a non-competitive technology. For, whenever his native skills come up against sophisticated technology, he invariably has to make way, and he loses his occupation and his moorings. Sophisticated technology with its semantic transducer, the English language, propagates unlimited-growth oriented devices. The average Indian is used to working in a non-growth situation in a conservative fashion. The marriage of the two technologies is a ✓ challenge of our time.

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APPENDIX I

Area needed to provide protein for one person using different sources (Vincent W.A. (1971): "Microbes and Biological Productivity", ed. C.G. Heden and Nils Molin, 47, Cambridge University Press)

Protein	Yield kg/ha/yr	Area yielding 29.2 kg/yr (m^2)
Meat from cattle on grassland	60	4 870
Wheat	300	970
Clover leaf protein	1 680	170
Chlorella pyrenoidosa	15 700	17.5
Spirulina platensis	24 300	12

APPENDIX II

CO_2 from Industrial Plants

1. An average value of coal analysis is:

   C:55.45 ; H:3.72 ; O:10.4 ; N:1.02 ; S:2.41 ; Moisture:15 ; Ash:12 ; Total:100.00

   For convenience this is rounded off to:

   C:55 ; H:4 ; O:10 ; N:1.5 ; S:2.5 ; H_2O:15 ; Ash:12

   This analysis is used next.

Basis: 1000 tonnes per day of Coal

Stoichiometric air required = 7440 t.p.d.
Air at 120% required = 8930 t.p.d.

Based on the gas analysis, a hypothetical flue gas is chosen as shown below:

Gas (weight percent): CO_2:20.6, H_2O:5.2, O_2:3.7, N_2:70, SO_2:0.5

Gas (Volume percent): CO_2:13.8, H_2O:8.55, O_2:3.54, N_2:73.5, SO_2:0.47

Gas (Hypothetical volume percent): CO_2:14, H_2O:8, O_2:4, N_2:74

These numbers are values in the range usually obtained.

2. Consider an ammonia plant of 1000 tonnes per day NH_3.

If we consider the synthesis gas: $1000 \times \frac{3H_2}{2NH_3}$ = 200 tonnes/day of H_2; the reforming reaction is:

$$C_nH_{2n+2} + nH_2O = nCO_2 + (3n+1)\ H_2$$

when n is 6, 8 or 10, the molar ratio of CO_2/H_2 is roughly 1/3. Therefore, for 200 t.p.d. H_2 we get about 1467 t.p.d. CO_2. This gas will not be available if there is a urea plant; however to clean the reformer gas, a gas absorption system for CO_2 is always used. Part of the tower liquid can be sent to algal culture. Also the small amount of NH_3, urea and biuret in the effluent can be used.

3. Consider a cement plant of 1000 tonnes/day. Approximately 1200 tonnes of limestone and 300 tonnes of coal will be used. Assume 1000 tonnes/day of $CaCO_3$ and 150 tonnes of carbon (in coal) are used:

$$CO_2 \text{ available} = 1000\left(\frac{CO_2}{CaCO_3}\right) + 150\left(\frac{CO_2}{C}\right)$$

$$= \underline{1000 \text{ tonnes/day}}$$

4. Each mole of alcohol from a distillery comes along with one mole of CO_2. ($C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$). Each tonne of alcohol will give 1 tonne of CO_2.

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